CHAPTER

# 15 The Physics of

## Getting Ready...

- Why does it take a train longer to stop than a car?
- Why does it take longer for a fast-moving vehicle to stop than for a slow-moving one?
- Why do collisions usually do less damage at lower velocities?
- Why do they say, "the bigger they are, the harder they fall"?

## Science Log

Have you ever been in a traffic situation where the driver had to make a tough choice? What decision was made? Was it wise? Explain.

Or

What decision would you make if you were in the situation described in the chapter opener? Explain and justify your choice.

Imagine this: you are driving on a busy one-way street to pick up some medications at the store. You are rested. There is nothing to distract you, and there are no medications or alcohol in your system. Your speed is within the posted limit. The road conditions are great. You are even following at a gap of two seconds!

Then, without warning, a car turns into your lane just ahead. No matter how fast your reaction time, one way or another you are going to hit something. You have a choice between the car that turned in front of you, the van to your left that is going in the same direction as you, or the row of parking meters to your right. What do you do?

You have three options. Which one will put you in the least amount of danger? That depends on several factors.

- How heavy are the objects?
- At what velocity are the objects moving?
- What direction is their motion?

In this chapter you will learn how mass and direction of the objects involved in a collision affect the severity of the damage. You will also have a look at how the forces act in a collision.

# Collisions

## What You Will Learn

In this chapter you will learn:

- why collisions with small objects cause less damage than collisions with large objects
- why it takes larger vehicles a longer time to stop than smaller vehicles
- why collisions are less severe at slower velocities
- why braking over a longer distance is easier than braking sharply
- what happens to objects after they collide

## Why It Is Important

- Velocity and mass both affect braking ability and collision damage. The time it takes to stop influences how the people in the vehicle will be affected by the stop. Knowing how these factors play a part in collisions will help you make better driving decisions.

## Skills You Will Use

In this chapter you will:

- calculate the momentum of colliding objects using their velocity and mass
- compare the momentums of different moving objects
- experiment with force, impulse, and momentum
- study the interactions between colliding objects

## Starting Point ACTIVITY

### Getting More Oomph

How can a dynamics cart be adapted to better push a box? What factors are important?

#### What You Need

dynamics cart
empty cardboard box 15–20 cm square
100 g mass
200 g mass
measuring tape or metre stick
stopwatch
plank of wood or other suitable ramp
8 books

#### What to Do

1. Set up ramp on a stack of four books. Make sure that the slope is moderate enough to allow you to raise the ramp later. Place the box at a measured distance away. Release the cart from the top of the ramp.
2. Time how long it takes the cart to travel from the start point to the box.
3. Record the distance the empty box travelled after being hit by the dynamics cart.
4. Add a 100 g mass to the cart, and repeat Steps 1 to 3. Repeat again using a 200 g mass. Try to use the same velocity for the cart each time.
5. Repeat Steps 1 to 3. This time, attempt to double the velocity of the moving cart by raising the cart up to double its original height. Record your observations.

#### What Did You Learn?

1. Do the analysis provided by your teacher.

# 15.1 Momentum and Mass

**DidYouKnow?**

Isaac Newton studied momentum. His first law of motion states that an object in motion will stay in motion until acted on by an outside force. Does that force need to be greater to stop a train than it needs to be to stop a bicycle?

**Figure 15.1** Which boat is easier to move or stop?

**DidYouKnow?**

A supertanker moving at 30 km/h may take 20 minutes and 5 km to come to a stop after the engines are shut off.

Imagine a swimmer in front of the above boats. Would the swimmer be able to stop the canoe? How about the tanker ship?

To answer these questions, you have to know a little about momentum and force.

- **Momentum** is a measure of an object's motion and how likely it is that the object will remain in motion.
- A **force** is any push or pull on an object. The size of the force required to move an object depends on how long you apply force, the mass of the object, and how fast you want to make the object go.

Objects that are not moving will not move until they are pushed or pulled with enough force. Objects that are moving will keep moving until enough force is added in an opposite direction to stop them. Objects with a lot of momentum will take more force and longer to stop.

**READING Check**

What factors determine the force required to move an object?

How does this relate to the boats in Figure 15.1?

- A swimmer is able to stop a canoe because the swimmer and canoe have a similar mass, and the canoe moves slowly enough that the swimmer can exert a force on the canoe for a long enough time to stop it.
- A swimmer cannot stop a ship because the ship is very heavy. As well, the ship is moving so fast that the person would not have time to exert a small force for long enough to stop the ship before being run over.

**Off the Wall**

For a mosquito to have the same momentum as a transport truck travelling at 100 km/h, the mosquito would have to be moving at 900 billion km/h!

**Figure 15.2** 554 km/h! The magnets in the track of this levitating train actually hold it up in the air. The friction that the train experiences is almost zero! That is how it can reach such super speeds.

## Calculating Momentum

Momentum is calculated by multiplying the mass of an object times the velocity it is travelling. Heavier and faster objects have more momentum.

The formula for momentum is:

momentum = mass × velocity

When calculating momentum, we usually express:

- mass in kilograms (kg)
- velocity in metres per second (m/s)
- momentum in kilogram metres per second (kg•m/s)

You will use this information in the Math Connect that follows.

**Figure 15.3** Why does this sign show a truck instead of a car?

READING Check

Write the formula for calculating momentum. Show the units for each part of the formula.

Math CONNECT

## Calculating Momentum

Use the following steps to help you calculate momentum when you know velocity and mass.

### Sample Problem

A 60 kg girl jogs at a pace of 4 m/s. What is her momentum?

### Steps in Solving It

1. *Write down what you know.*
   mass = 60 kg
   velocity = 4 m/s
   momentum = ?
2. *What do you want to find out?*
   What is her momentum?
3. *Use the formula.*
   momentum = mass × velocity
   = 60 kg × 4 m/s
   = 240 kg•m/s
4. *State your findings.*
   The girl's momentum is 240 kg•m/s.

### Solve These

Use the example above to help you fill in the missing parts in the chart that follows. Be sure to show all your calculations.

| Object | Mass | Velocity | Momentum |
|---|---|---|---|
| adult female fly | 0.000 012 kg | 5 km/h (1.5 m/s) | |
| adult female human | 70 kg | 5 km/h (1.5 m/s) | |
| adult female on 5 kg bicycle | 75 kg | 30 km/h (9 m/s) | |
| adult female and motorcycle | 250 kg | 50 km/h (15 m/s) | |
| compact car | 750 kg | 50 km/h (15 m/s) | |
| compact car | 750 kg | 100 km/h (30 m/s) | |
| transport truck | 2500 kg | 50 km/h (15 m/s) | |
| transport truck | 2500 kg | 100 km/h (30 m/s) | |

## DidYouKnow?

The black mark left on the pavement when you "burn rubber" is caused by friction between the tire and pavement. The friction creates heat, which melts the rubber. A little of the melted rubber is left on the pavement.

## Slowing Momentum

As every cyclist and driver knows, the best way to counteract momentum is by **braking**. Brakes apply a force that stops vehicles by decreasing their momentum.

Brakes work using **friction**. Friction is the force that two objects exert on each other when they press against each other. Braking uses friction in two ways:

- Applying the brake pedal activates machinery that presses brake pads against the inside of brake drums on the vehicle's wheels. That is one source of friction that slows momentum.
- There is also friction between the vehicle's tires and the surface of the road. During braking, this friction reduces momentum.

Brakes work best in dry conditions when the brake machinery is in good condition. Worn brakes do not work as quickly against momentum. In addition, roads that are slippery due to rain, ice, or snow will reduce the amount of friction and therefore slow the speed of braking.

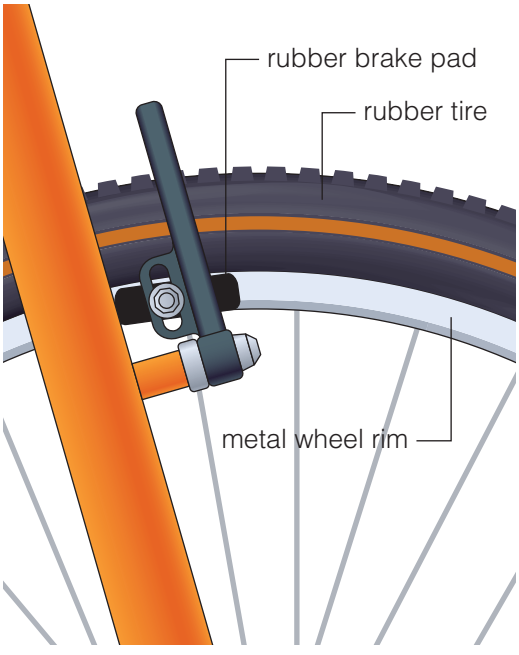
READING Check

Why do icy roads reduce braking ability?

Friction also works with canoes and kayaks, in which you can stop paddling and gradually glide to a stop.

In the Find Out activity that follows, you will investigate how mass affects braking distance.

**A. Bicycle Brakes**




**B. Car Brakes**

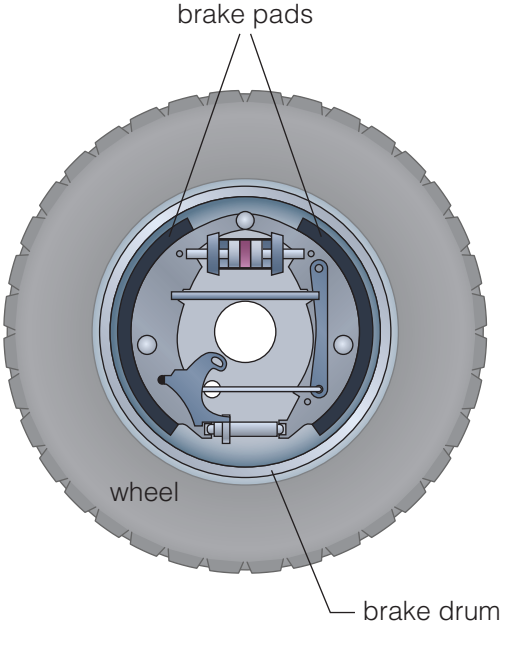



**Figure 15.4** Bicycle brakes and car brakes work in essentially the same way — pads press against the wheel until the friction slows the wheels.

Find Out ACTIVITY

## Friction, Mass, Force, and Stopping

If you let a dynamics cart roll down a ramp, it will travel a certain distance along the floor before friction in the wheels and between the wheels and the floor brings it to a stop. In this activity, you will study how the mass of the cart affects the distance it travels.

### What You Need

- balance
- ramp
- dynamics cart
- 100 g mass
- 500 g mass
- measuring tape or metre stick

### What to Do

1. Clear a large path for your cart to travel. It should stop on its own.
2. Find the mass of the dynamics cart.
3. Release the cart from the top of the ramp. Measure and record how far it travels before it stops.
4. Repeat Step 3 using a 100 g mass in the cart, and then a 500 g mass. Measure and record how far the cart travels.

SKILL CHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

### What Did You Discover?

1. **(a)** What made the cart go farther before stopping on its own?
   **(b)** What does this suggest about the relationship between mass and momentum?
2. **(a)** Consider your answer to 1(b). How is mass related to stopping distance?
   **(b)** Why does it take so long for a freight train to stop?
3. Graph the mass added to the dynamics cart and the distance travelled from the bottom of the ramp. Place mass on the *x*-axis and distance on the *y*-axis. Do you notice any mathematical relationship between how much mass is added and how much farther the cart travels before stopping?

### Extension

4. Would the cart roll farther on a smooth floor surface or on carpet? Develop a procedure. Predict what you think will happen, then do some trials to test your hypothesis.

## Check Your Understanding

1. Usually, the faster something is moving, the longer it takes to stop. Explain a situation where it might be harder to stop a vehicle moving at 30 km/h than one moving at 60 km/h.
2. Give an example of a moving object with very low momentum, and an example of one with a high momentum. Explain your choices, using the definition of momentum.
3. Explain how momentum is affected by each of the following:
   **(a)** doubling the velocity
   **(b)** doubling the mass
   **(c)** doubling both the velocity and mass

**Key Terms**

- momentum
- force
- braking
- friction

# 15.2 Changing Momentum Is Related to Force

**DidYouKnow?**

Isaac Newton wrote most of the laws about forces. The unit for force ($kg \cdot m/s^2$) is called a newton (N) in his honour.

As you approach an intersection, you can see the light turning amber. You begin braking softly, and the force of friction created by your brakes slows your vehicle. Your velocity decreases slowly, as does your momentum (remember mass × velocity = momentum). Your body continues forward slightly.

Because your body has its own momentum, you need a force to slow *it* as well. The seat belt provides that restraining force. Because you are taking a long time to brake, that force will be small.

Forces, like friction, can be large or small. You can brake hard or gently.

Forces can also either act for a short time or a long time. In our example, you brake gradually for a long time (small force × long time). If you were to brake hard, the car would stop quickly, and you would feel a great force (large force × short time).

**READING Check**

What is an impulse, and how does it affect the momentum and velocity of an object?

Either way, the result would be the same. The car would go from a certain velocity (and therefore momentum) to zero velocity. The combination of the size of the force and the time during which the force acts is called **impulse**. Impulses change momentum — either increasing or decreasing it. The bigger the impulse is, the bigger the change in momentum will be.

impulse = force × time

**Figure 15.5** This sumo wrestler is at rest. If you wanted to move him (give him some momentum), you would have to try to do the opposite of what you would do in a traffic situation. You would have to apply a large force to start momentum.

Table 15.1 provides a visual review of what is discussed above. Notice what happens to the impulse as force and time change.

**Table 15.1** What Happens to Impulse When Force and Time Change?

| force | × | time | = | impulse | (change in velocity or momentum) |
|---|---|---|---|---|---|
| large | | long | | large | large |
| large | | short | | medium | medium |
| small | | long | | medium | medium |
| small | | short | | small | small |

## Measuring Impulse

When working with impulse, you will work with specific measurements. These include:

- impulse — This is measured in $kg \cdot m/s$.
- force — This is measured in $kg \cdot m/s^2$ or newtons (N).
- time — This is measured in seconds (s).

Math CONNECT

## Calculating Impulse

Use the information on measuring impulse and the formula as you work through this Math Connect.

### Sample Problem

A car is hit from behind by an identical car with a force of 50 000 kg•m/s$^2$. Both cars come to a stop within 2 seconds. What impulse was experienced?

### Steps in Solving It

1. *Write down what you know.*
   force = 50 000 kg•m/s$^2$ or 50 000 N
   time = 2 s
   impulse = ?
2. *What do you want to find out?*
   What is the impulse?
3. *Use the formula.*
   impulse = force × time
   = 50 000 kg•m/s$^2$ × 2 s
   = 100 000 kg•m/s
4. *State your findings.*
   The impulse of the object in this example is 100 000 kg•m/s.

### Solve These

Use the example to help you solve the following problems. Be sure to show all your calculations.

1. A football player collides with another player. The force of the collision is 1000 kg•m/s$^2$. The collision lasts 1 second. What is the impulse?
2. What would be the impulse created by the same force of tackle (1000 kg•m/s$^2$), but this time lasting for 2 seconds?
3. A baseball player feels a frictional force of 400 N as she slides into home. What is the impulse if the slide lasts 0.5 seconds?
4. What would the impulse be if the same slide lasted 2 seconds?

## Impulse and Force

Compare your answers to problems 1 and 2, and then compare your answers to problems 3 and 4, in the above Math Connect. What happens to the impulse if the force is applied for a longer period of time?

If you did the problems correctly, you should notice that the impulse (or change in momentum) increases as force is applied over a longer period of time. Impulse also increases if a larger force is applied.

- A force of 500 N over 2 seconds will have a greater impulse than a force of 50 N over 2 seconds.
- A force of 50 N for 5 seconds will have a greater impulse than a force of 50 N for 2 seconds.

A large impulse can change momentum a great deal. This means that:

- You can change momentum by applying a greater force.
- You can change momentum by applying a force for a longer period of time.

Which method of changing momentum would you want to use to avoid a collision? Which method would you use if you wanted to move a house without damaging it?

READING Check

List three different ways to change momentum.

DidYouKnow?

8000 kg•m/s$^2$ or 8000 N is the maximum amount of force some brakes are able to apply. The force of gravity is 14 740 N and acts constantly. Which has greater impulse?

Find Out ACTIVITY

## Objects at Rest, Objects in Motion

When you push an object, it gains velocity and momentum. What happens when you push an object that is connected to another one in some way?

How can you remove the tablecloth without moving the dishes?

SKILL CHECK

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

### What You Need

dynamics cart

small plastic figurine

### What to Do

1. Set the plastic figurine in the dynamics cart.
2. Push the cart forward by hitting it from behind. What happens to the passenger?
3. This time, speed up the cart gradually and stop it immediately. What happens to the passenger?

### What Did You Find Out?

1. Describe what you see happening to the passenger in both cases. Use the key word "impulse."
2. If you wanted to remove a tablecloth from a table without moving all the dishes, how might you do it? Why would this work?

**Try This!**

Work outside in pairs. Each pair gets one egg. How can you throw the egg so your partner catches it without cracking the shell or breaking it? Use the information in the Impulse and Force section to develop a technique.

**Key Terms**

impulse

## Check Your Understanding

1. How can you increase the time interval that you use to stop for a red light?
2. How does increasing your stopping time protect you from injury?
3. Is the force needed to stop a car the same whether you take a long time to stop or a short time? To answer this, use the equation for impulse and show your calculations and thinking.
4. Using an example of each, describe the difference between momentum, force, and impulse.
5. Imagine the same rear-end collision as in the sample problem on page 275. This time, the brakes fail in the car in the rear. The same force (50 000 $kg \cdot m/s^2$) now lasts 5 seconds as the car in the rear continues to drive forward. What is the impulse in this example?

# 15.3 Changing Momentum Quickly

Drivers frequently drive at 100 km/h (28 m/s) and stop safely without injuring themselves or damaging their vehicles.

Imagine the force you would feel if your vehicle went from 100 km/h (28 m/s) to a complete stop in less than one second! This is what occurs in a crash, and the forces involved are great enough to crumple metal, shatter glass, and splinter bones.

The difference in the two stops is the time involved. Fast stops require a large impulse that results in an immediate change in momentum. In order to do this, a large amount of force is required. This force is what causes injury and property damage during collisions.

The Math Connect on page 278 shows the difference in impulse between these two examples.

In both examples, note that several factors were the same.

- The change in velocity was the same.
- The change in momentum was the same.
- The impulse was the same.

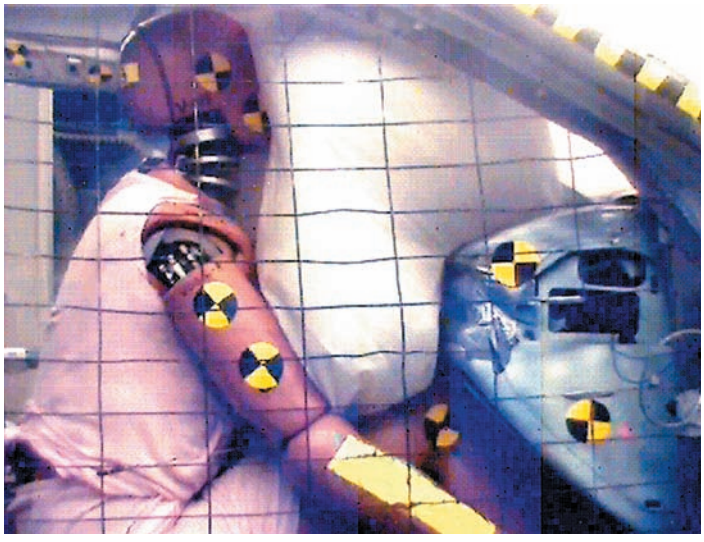


**Figure 15.6** Seat belts, air bags, and other safety features help to slow passenger momentum, even when the car experiences a large impulse. The car and passenger experience the same impulse during this crash. The car experiences the impulse in a very short time (large force). The passenger, however, feels it over a longer time as the seat belt and air bag slow momentum gradually. More time = less force.

**READING Check**

How is the force of a collision related to the time it takes for a change in momentum?

Only the amount of time it took to achieve a change in velocity was different. It is this time difference that makes the difference between a small force and a great one. This difference in force may also be the difference between life and death for a vehicle's passengers. Figure 15.7 shows why.

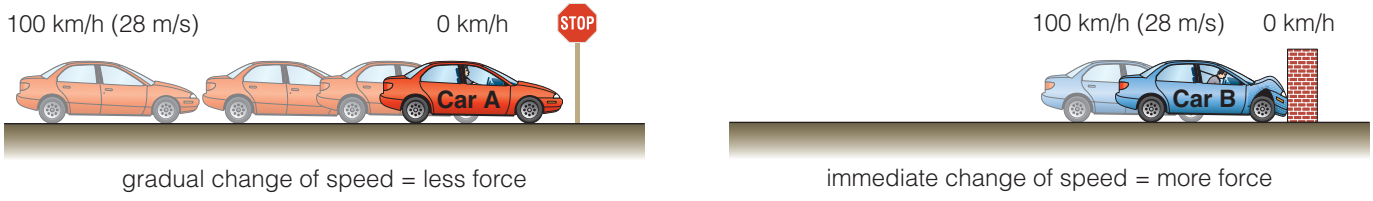



**Figure 15.7** These two cars were travelling at the same velocity. Car A braked and stopped over 25 seconds. Car B ran into a brick wall and stopped in 1 s. Which driver will experience a greater force? Explain. Use the information in the Math Connect on the next page to prove your point.

Math CONNECT

# Calculating Force

When an impulse occurs, momentum changes. Usually, the mass stays the same and the velocity changes.

The amount of time it takes to change velocity determines the force involved. For example, it takes more force to stop a car going 100 km/h in 1 s than it does to stop the same car in 25 s.

To find the force involved in such a stop, you can use the following formula:

$$\text{force} = \frac{\text{mass} \times \text{change in velocity}}{\text{time}}$$

## Sample Problem

What force is involved in stopping a 1200 kg car travelling at 100 km/h (28 m/s) in 25 seconds?

### Steps in Solving It

1. *Write down what you know.*
   mass = 1200 kg
   change in velocity = final velocity ($\text{velocity}_2$) - starting velocity ($\text{velocity}_1$)
   = 0 m/s - 28 m/s
   = -28 m/s (the negative means the vehicle is slowing down)
   time = 25 s

2. *What do you want to find out?*
   What force is involved?

3. *Use the formula.*
   $$\text{force} = \frac{\text{mass} \times \text{change in velocity}}{\text{time}}$$
   $$= \frac{(1200\ \text{kg}) \times (-28\ \text{m/s})}{25\ \text{s}}$$
   $$= \frac{-33\,600\ \text{kg•m/s}}{25\ \text{s}}$$
   $$= -1344\ \text{kg•m/s}^2$$

4. *State your findings.*
   The car experienced a negative or braking force of 1344 kg•m/s$^2$. **Note:** This is Car A in Figure 15.7 (on page 277).

## Solve These

Use the example above to help you solve the following problems. Be sure to show all your calculations.

**1. (a)** During a race, a 1200 kg car slowed down to 100 km/h (28 m/s) just before it hit a brick wall. It stopped in 1 s. What force was involved? **Note:** This is Car B in Figure 15.7 (on page 277).

**(b)** How much larger is this force than the force in the sample problem?

**2.** A sport utility vehicle with a mass of 2000 kg is travelling at 100 km/h. The driver brakes to avoid a small animal in the road. The velocity changes from 28 m/s (100 km/h) to 8 m/s (30 km/h) in only 2 seconds. What force does the vehicle experience?

**3. (a)** A 1500 kg car collides with a roadside barrier, and the car's velocity changes from 28 m/s (100 km/h) to 0 m/s in 0.5 seconds. What force does the vehicle experience?

**(b)** How many times larger is this force than the force in question 2?

Disc CONNECT

To learn more about momentum, load the student CD-ROM onto your computer. Launch the **Crash Test** applet and follow the instructions.

CONDUCT AN

INVESTIGATION 15-A

SKILL CHECK

Initiating and Planning

Performing and Recording

Analyzing and Interpreting

Communication and Teamwork

# Collision Damage

How does the velocity of a collision affect the severity of the damage done? Does it matter if you hit a brick wall or a parking meter?

## Problem

How will the velocity of the vehicle and the mass of any item that is hit affect the passenger?

## Predictions

1. How will the velocity of the car affect the distance the passenger flies?
2. How will the velocity of the car affect the damage to the passenger?
3. How will the mass of the barrier affect the motion of the car and passenger after the collision?

### Apparatus

wooden ramp

toy car

metre stick

heavy barrier (for example, a stack of textbooks)

light cardboard barrier

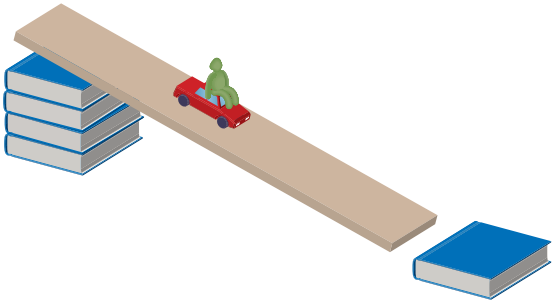
### Materials

soft clay cube to make into a passenger

chalk

## Procedure

1. Set up the ramp as shown in the diagram. Make sure the light barrier is lower than the car, so the clay model is able to fly free.



2. Place the clay model on the car. Begin releasing the car from the lowest mark on the ramp.
3. Mark off with chalk where the passenger landed, and measure the distance from the crash point. Record this distance and the damage to the passenger.
4. Repeat Steps 1 to 3 for all three heights of the ramp, re-forming your passenger after each collision.
5. Repeat Steps 1 to 4 using the heavy barrier.

## Analyze

1. Describe what happened to the car in terms of velocity and momentum.
2. **(a)** How was the force of collision different in the collisions with the heavy and light barriers?

   **(b)** What caused the difference in force between the two trials in this investigation?
3. Graph the distance the clay passenger flew after each run. On the $x$-axis, place the distance in cm that the car travelled down the ramp. On the $y$-axis, place the distance the passenger flew.

## Extend Your Skills

4. Add masses to the car. What happens to the distance the passenger flies?

## Check Your Understanding

1. How does the change in momentum compare between a quick stop (collision) and a controlled stop (braking) from the same velocity? Why?
2. In a collision that stops a vehicle, how does the original velocity relate to the force experienced by vehicle and passenger? Explain your answer using the terms "impulse" and "time."
3. If you lengthen the time a change in velocity takes, will the force go up or down? Use the equation force $= \frac{\text{mass} \times \text{change in velocity}}{\text{time}}$ to support your response. Substitute some reasonable numbers for mass, velocity, and time to prove the effect.

# 15.4 Is Momentum Lost?

When an object slows down, momentum appears to be lost. Where does it go?

The energy of movement is changed to other kinds of energy.

- Friction in the brakes, and between the tires and the road, causes heat. In some crashes, this heat is enough to ignite the vehicle.
- Energy may also be lost in crumpling metal and shattering glass.

READING Check

What happens to the energy of movement when momentum is lost?

In many collisions, momentum is *not* all lost. Objects that collide continue to move in some direction. The amount of momentum lost will vary with the conditions and circumstances.

### Conservation of Momentum

Imagine two vehicles travelling along a road in the same direction. Each has its own momentum. Since people usually refer to car velocities in km/h, we will use these units when calculating vehicles' momentum.

Now picture the vehicle behind rear-ending the vehicle in front. What happens to the momentum of each vehicle?

- The momentum of the vehicle in front will increase as it is pushed forward. It experiences a positive force.
- The momentum of the vehicle behind will decrease as the vehicle slows down because of the impact. It experiences a negative force.

READING Check

Use a rear-end collision to explain the Law of Conservation of Momentum.

Scientists have calculated the momentum of vehicles before and after a rear-end collision. Their calculations show that, under ideal conditions where friction is minimal and the vehicles lock together, the total momentum between the two vehicles does not change. This is also true if one vehicle bumps into another and there is no damage. During such a collision, one vehicle will lose momentum at the same rate that the other gains it.

You have heard of the Law of Conservation of Energy and the Law of Conservation of Mass. Momentum is also conserved. The **Law of Conservation of Momentum** means that the total momentum of two colliding objects stays the same after their collision.

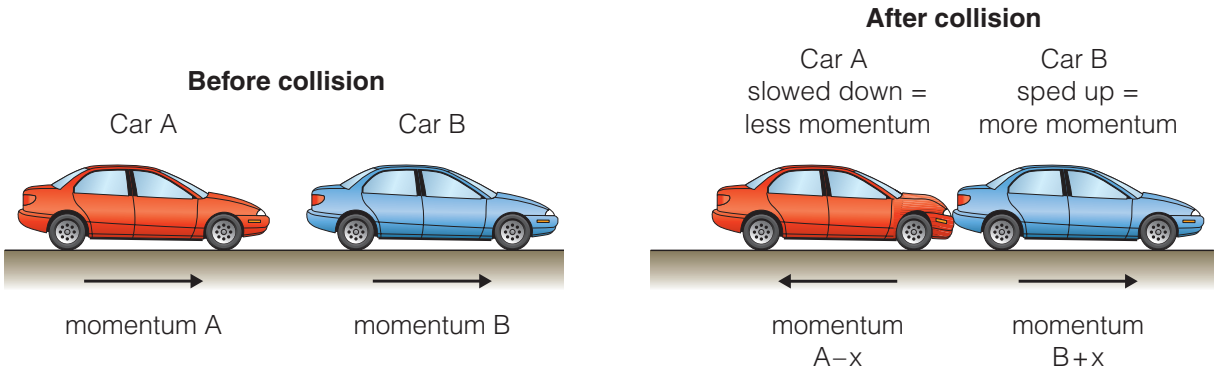



**Figure 15.8** This rear-ender occurred on an icy road (therefore minimal friction) and locked the vehicles together. Imagine the momentum of each vehicle before and after the collision. Before the collision, Cars A and B were travelling at about the same velocity along the highway and had close to the same momentum. After the collision, the momentum of Car A has decreased — hitting Car B caused a negative impulse; this is the "−x" in the equation on the left. The momentum of Car B has increased — being hit by Car A caused a positive impulse; this is "+x" in the equation on the right.

Notice that the momentum of one vehicle *decreased* by the same amount that the momentum of the other vehicle *increased*.

## Head-on Collisions

How does the Law of Conservation of Momentum apply to head-on collisions? Consider this.

Two vehicles are travelling along a highway in opposite directions. They have the same momentum. They hit head on. What happens?

Both objects are in motion and have the same momentum. The motion is in the opposite direction. The forces would cancel each other out. Their **total momentum** would be zero, and so would their velocity. They would stop completely (with a lot of crumpling and injury to the people inside).

If one vehicle had greater momentum than the other, that vehicle would add momentum to the other vehicle, which would then move backward.

**READING Check**

How does a head-on collision illustrate the Law of Conservation of Momentum?

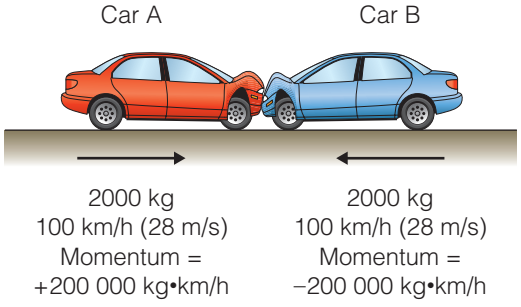



**Figure 15.9** Cars A and B have the same mass and velocity. As a result, they have the same momentum. Note that the momentum of Car A has a positive sign (+) in front of it because Car A is moving to the right. Car B is moving to the left, so a negative sign (−) is used to indicate this opposite momentum.

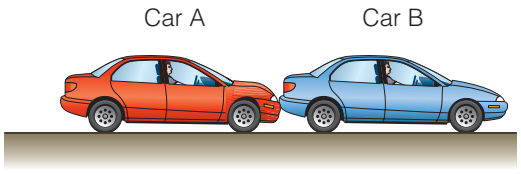
What happens when the two cars collide? The value of their momentums will cancel each other out (−200 000 kg•km/h + 200 000 kg•km/h = 0). They will stop.

Hitting another vehicle head-on is like hitting a brick wall at the combined velocities of the two vehicles. Although the momentums cancel each other out, the force is enough to kill.

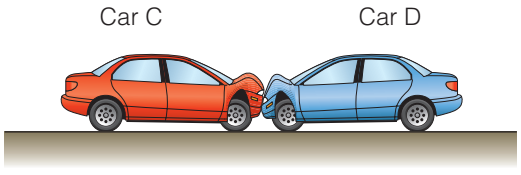
**Try This!**

With a partner, show what would happen during the following head-on collisions:

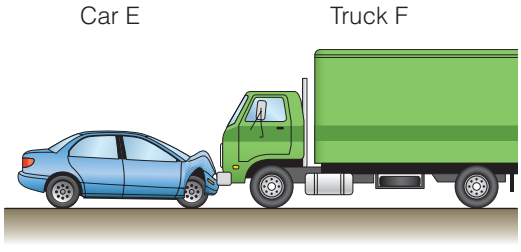
- Cars A and B have the same momentum and hit head-on.
- Car A has greater momentum than Car B. They hit head-on.
- Car B has greater momentum than Car A. They hit head-on.




**Collision 1**




**Collision 2**




**Collision 3**

# Momentum Changes in a Collision

## Think About It

What happens to momentum in each of the collisions shown?

## What to Do

1. Copy the visuals for each of the collisions into your notebook. Underneath each vehicle, describe what will happen to the vehicle's velocity and momentum.
2. Draw a line out from each driver and describe what you think will happen to each driver.

## Analyze

1. Briefly describe how the momentum of each vehicle has changed during each collision.
2. Explain how each collision illustrates the Law of Conservation of Momentum.
3. How does each driver's movement during the collision compare with the action of the vehicle being driven?
4. Draw Collision 1 again. This time, make Car B half the size of Car A.
   **(a)** How much will this change the momentum of Car B compared to Car A?
   **(b)** How will this change the result of the collision?

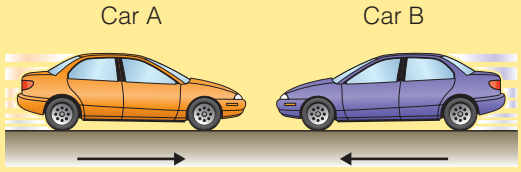
**Off the Wall**

When a bug hits your windshield, both the windshield and the bug experience the same amount of force. In fact, the bug slows your car a little. However, the bug has its velocity changed more dramatically because of its small mass.

Math CONNECT

## Calculating Final Momentum

Use the information about each collision to calculate the final momentum of the vehicles involved.




### Sample Problem

Two cars with the same mass are travelling at different velocities. Car A is travelling at 100 km/h to the right. Car B is travelling at 60 km/h to the left. Car A has a momentum of +200 000 kg•km/h. Car B has a momentum of −120 000 kg•km/h.

(a) Calculate their total momentum.

(b) Which way will the vehicles move during a collision?

### Steps in Solving It

1. *Draw what is happening.*
2. *Write down what you know.*
   momentum of car A = +200 000 kg•km/h
   momentum of car B = −120 000 kg•km/h
3. *What do you want to find out?*
   The total momentum.
4. *Add the two momentum figures.*
   +200 000 kg•km/h + −120 000 kg•km/h = +80 000 kg•km/h
5. *State your findings.*
   Both cars will move to the right. (Keep in mind that the bodies inside the cars continue to move with their original velocities and directions, unless restrained by seat belts or other safety devices.)

### Solve This

Use the example above to help you solve the problem that follows. Draw a diagram. Show all your thinking and calculations.

**1.** A transport truck with a mass of 10 000 kg and a car with a mass of 2000 kg are travelling at the same velocity (100 km/h) but in opposite directions. The truck is travelling to the left, and has a momentum of −1 000 000 kg•km/h. The car is moving to the right, and has a momentum of +200 000 kg•km/h. What is the total momentum after the collision? In which direction will these vehicles move if they collide?

## Check Your Understanding

**1.** Use a series of diagrams to illustrate the Law of Conservation of Momentum. Include a calculation showing the total momentum.

**2.** Two vehicles are moving toward each other. The westbound vehicle has a momentum of 500 000 kg•km/h, while the eastbound vehicle has a momentum of 250 000 kg•km/h. If the two vehicles collide without braking, which way will they continue moving after the collision? Draw a diagram to illustrate your answer.

**Key Terms**

Law of Conservation of Momentum
total momentum

CHAPTER

# 15 Review

## Key Terms

momentum
force
braking
friction
impulse
Law of Conservation of Momentum
total momentum

## Reviewing Key Terms

If you need to review, the section numbers show where these terms were introduced.

**1.** Define each of the following terms. Include a math formula if one applies.

**(a)** force (15.1)

**(b)** impulse (15.2)

**(c)** momentum (15.1)

**2.** Use a labelled diagram to illustration the Law of Conservation of Momentum. (15.4)

**3.** Use an equation and scenario to explain total momentum. (15.4)

## Understanding Key Ideas

Section numbers are provided if you need to review.

**4.** Why does it take longer for large objects to stop than small objects? (15.1)

**5.** Explain how momentum is conserved when a car hits a bicycle. (15.1)

**6.** How do brakes work to stop your car? (15.1)

## Developing Skills

**7.** Examine this photograph and consider what you have learned about momentum and force during this chapter. Use what you have learned to answer the questions.

**(a)** What causes a rocket ship to start moving upward? (15.1)

**(b)** Does the shuttle continue to move after the forces are removed? Why or why not? (15.1)

**(c)** When the shuttle needs to alter its course in outer space, the engines or thrusters will fire. If the thrusters on the left of the shuttle fire, which direction will the shuttle move? (15.1)

**(d)** When astronauts take a space walk, they leave a ship that is orbiting Earth at close to 30 000 km/h.

- How fast are they moving as they leave the ship? (15.4)
- What forces do they feel once they are in open space? (15.4)

**(e)** If one astronaut throws a ball at the other, in which direction does the thrower move? (15.4)

**(f)** Which direction will the catcher move in when she catches the ball? (15.4)

**(g)** When the second astronaut catches the ball, what will happen to the velocity and momentum of both the ball and the astronaut ("up" and "down" can be used in your answer)? (15.4)

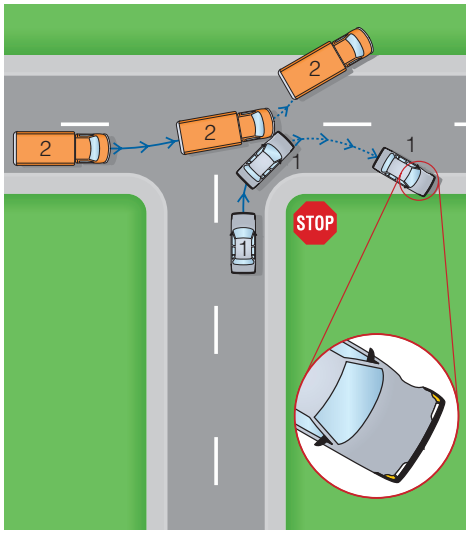
**8.** Working with a partner, create a new demonstration that illustrates one of the concepts from this chapter. Present and explain your demonstration to the class. Be creative. (15.1, 15.2, 15.3, 15.4)

**9.** This figure shows a collision involving a car and a much larger truck. The areas of damage are highlighted in red. (15.2, 15.3)

**(a)** Looking at the change in direction of both vehicles after impact, can you determine which vehicle was moving faster? Explain.

**(b)** Looking at the distance each vehicle travelled before stopping, can you determine which one was moving faster? Explain.

**(c)** Which vehicle do you think will have the greater damage? Why?




## Problem Solving/Applying

**10.** Draw a diagram of the following scenario. Show your thinking and work for each calculation. (15.4)

**(a)** A 18 000 kg transport truck is travelling east at 80 km/h. Calculate the momentum of the truck.

**(b)** A 1000 kg car is travelling west at 140 km/h. Calculate the momentum of the car.

**(c)** If the driver of the car falls asleep, crosses the median, and hits the transport truck head-on, calculate the final momentum.

**(d)** In which direction will the vehicles move?

**11.** Calculate the impulse that a truck experiences if the brakes apply a force of 6000 kg•m/s$^2$ for 10 seconds. (15.2)

## Critical Thinking

**12.** How could you tell if there was a difference in mass between two similar objects without lifting them? (15.2)

**13.** People often shake a ketchup bottle to get the ketchup out. Use the terms "momentum," "force," and "impulse" to explain why they do this. (15.2)

**14. (a)** How is knowledge of momentum useful for police officers doing an accident investigation? (15.2)

**(b)** What information would an officer record when arriving at a collision scene to help determine what occurred? (15.2)

**(c)** What questions would an officer ask the drivers to help reconstruct the situation? (15.2)

**15.** Pilots who fly the fastest aircraft can experience blackouts and/or temporary loss of vision if they speed up too rapidly. The blood in their brains gets physically sucked to the back, where the visual cortex is. Use what you know about momentum to explain how this occurs. (15.3)

### Pause & Reflect

1. Describe two safety features of a vehicle. How do they work with and against momentum?
2. Many people feel very safe because of the safety features in their vehicles. Develop a one-minute explanation to convince them of the dangers involved in automobile collisions.